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AN RF INTRUSION SENSOR FOR ISOLATED RESOURCES.(U)

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RADC-TR-77-118
IN-HOUSE REPORT
MARCH 1977

An RF Intrusion Sensor for Isolated Resources

NICHOLAS V. KARAS
PETER R. FRANCHI
RONALD L. FANTE
J. LEON POIRIER

ROME AIR DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
GRIFFISS AIR FORCE BASE, NEW YORK 13441

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APPROVED: Walter Rotman

WALTER ROTMAN, Chief
Microwave Detection Techniques Br.
Electromagnetic Sciences Division

APPROVED: Allan C. Schell

ALLAN C. SCHELL
Acting Director
Electromagnetic Sciences Division

FOR THE COMMANDER: John P. Huss

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United States Air Force
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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE — READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: RADC-TR-77-118 (14)
2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER (9) Technical rept.
4. TITLE (and Subtitle): AN RF INTRUSION SENSOR FOR ISOLATED RESOURCES. (6)
5. TYPE OF REPORT & PERIOD COVERED: In-House
6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): (10) Nicholas V. Karas, Ronald L. Fante, Peter R. Franchi, J. Leon Poirier
8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Deputy for Electronic Technology (RADC/ETEP), Hanscom AFB, Massachusetts 01731
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 62702F, 46001501
11. CONTROLLING OFFICE NAME AND ADDRESS: Deputy for Electronic Technology (RADC/ETEP), Hanscom AFB, Massachusetts 01731
12. REPORT DATE: (11) March 1977
13. NUMBER OF PAGES: 30
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): (12) 31p.
15. SECURITY CLASS. (of this report): Unclassified
15a. DECLASSIFICATION DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report): Approved for public release; distribution unlimited. (16) 4600 (17) 15
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)
18. SUPPLEMENTARY NOTES
19. KEY WORDS (Continue on reverse side if necessary and identify by block number):
Intruder detection
VHF detection
Aircraft security
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The application of VHF techniques to the problem of intruder detection around isolated resources was investigated. A number of possible configurations are discussed and the results of some preliminary measurements are presented. It was found that the shape of the protected zone could be made toroidal or hemispherical depending on the deployment of the sensor cables. Operation at 75 MHz demonstrated the high sensitivity of VHF signals to adult intruders and their insensitivity to changes in ambient environmental over

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conditions. Specific system responses to intrusions by a human and by an animal are shown. Both the radial and the circumferential sensitivity of the system to various modes of human locomotion (walking, creeping, crawling, and rolling were investigated).

Finally, areas that need additional investigation are identified and some specific recommendations made.

Preface

The authors wish to thank all the other members of the Microwave Detection Techniques Branch who contributed their help. Particular thanks is extended to Branch Chief Walter Rotman for initial impetus and then overall guidance, to John D. Antonucci for field help, and to David H. Tropea for expert technical assistance.

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Illustrations

An RF Intrusion Sensor for Isolated Resources

1. INTRODUCTION

No system now available can provide adequate all-weather intruder protection for high value isolated resources. A number of approaches have been aimed at developing reliable intruder detection systems for parked aircraft. These have not generally been successful because of inherent limitations in the techniques that were applied. This report describes some initial investigations of an experimental radio frequency intruder detection technique which promises significant advantages over existing approaches. The method can be applied to structures, vehicles, or even military positions.

The purpose of any such system is to protect an isolated resource such as a large parked aircraft by surrounding it with a sensor system which defines a zone around the resource. Any intrusion within this zone is detected and an alarm sounded. Radio frequency signals in the VHF range are particularly useful for this application. For example, unlike optical[1] and infrared sensors,[2] radio frequency sensors are not affected by snow, rain, fog, dust, darkness, or other

(Received for publication 30 March 1977)

1. Burngard, D. R. et al (1973) Equipment Description of a Mobile Laser Fence for Aircraft Security, Working Paper No. 5430, Dept D-82, The Mitre Corporation.
2. Monostatic Infrared Intrusion Detector "MIRID" (1970) Engineering Bulletin, Motorola/Government Electronics Division, 17, No. 2:18-21.

environmental factors. Doppler[3] and beam breaker radars,[4-6] which operate at microwave frequencies, also exhibit severe operational problems. The former, deployed under an aircraft, are subject to shadow effects from the landing gear structure. The latter normally require three or four units to protect a single resource and are subject to blind spots. Other sensors operating at various frequencies and using different detection techniques have been investigated and none has yet been found suitable. The most severe problem common to all systems now available is their high false-alarm rate and low detection sensitivity under certain environmental conditions.

The goal of the technique to be described is to exploit the inherent and unique properties of VHF signals in order to eliminate or greatly reduce the limitations of previous systems. In particular, at these frequencies the response due to human (size) intruders is enhanced and that due to smaller animals is greatly reduced. Also VHF signals are not affected by environmental effects. These properties together lead to a system which has a high detection sensitivity coupled with a low false-alarm rate.

The investigations outlined in this report are preliminary but do, in fact, demonstrate the feasibility of applying VHF techniques to develop a simple, reliable, and easily deployable intruder detector system.

2. SCALE MODEL MEASUREMENTS

The problem of protecting an isolated structure from unauthorized intruders can be approached in several ways. One technique, applied to parked aircraft, was to measure the capacitance between the metal aircraft and the ground underneath. When an intruder approached the aircraft, the capacitance changed and triggered an alarm. It was found, however, that the measured capacitance also depended on such factors as tire type, gas load, rain, and humidity, and changed markedly as the wings moved in the wind. These factors that raised the false-alarm rate, coupled with the difficulty of setting up the system, made it unsuitable for reliable use.

3. Mid-Range Microwave Intruder Detector, Shorrock Security Systems, Ltd, North American Office, 1815 North Fort Myer Drive, Suite No. 1002, Arlington, VA 22209.

4. Lightweight Portable Microwave Barrier Type Intrusion Sensor "AIDS-300," General Dynamics, Electronics Division, P.O. Box 81127, San Diego, CA 92138.

5. Woode, A.D. and Charters, J.S.T. (1976) Microwave Systems News, August/September, pp 113-118.

6. Outdoor Microwave Link, Model 300, Omni Spectra, Inc., Security Products, 1040 West Alameda Drive, Tempe, Arizona.

It was thought that in contrast to this, an RF system could be made to depend on the characteristic dimension of the aircraft and not on its critical spacing above the ground. This would be achieved by energizing the aircraft at one of its resonant frequencies. Much work has been done in the past in inducing high frequency radiating currents on airplane surfaces;[7] this information could be applied to the present problem.

When energized near resonance it was expected that the system would be most sensitive (a good detector) to external intruder disturbances. A number of laboratory measurements were carried out with the model shown in Figure 1 in an attempt to find the best methods of energizing the aircraft and suitable techniques for detecting intrusions. The general approach was to drive the aircraft against a conducting surface on the ground under the plane. The ground returns investigated included wire loops, plates, single-strip and multiple-strip conductors of various sizes. Some of the combinations that were tried are listed in Appendix A.

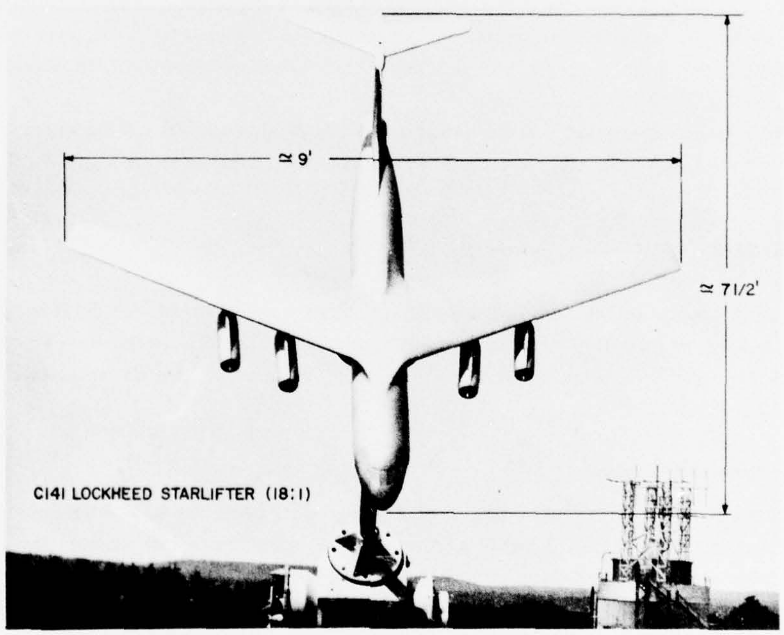

Figure 1. Photograph of Model Airplane

7. Tanner, R. L. (1957) Shunt-Fed and Notch-Fed H-F Aircraft Antennas, AFCRC-TN-57-582, AD 133622, Stanford Research Inst., Menlo Park, CA.

The RF characteristics of the model working against the chosen ground were monitored with a network analyzer and variations in system Q, resonant frequency, or impedance were used to compare the detection sensitivity of one setup with another.

These configurations could be treated as tuned circuits or transmission-line systems depending on how they were connected and which system terminals were monitored. However, in every mode investigated the problems found were similar. It was difficult to resonate the airplane; the detection sensitivity was more dependent on the plane's location relative to other nearby objects than on its characteristic dimension, and the perturbation produced by a scaled intruder was very small. Although the results of this approach were disappointing, it was applied with some success to an automobile as outlined in Appendix B.

Gradually, as a result of these experimental measurements, a new configuration evolved. A receiving loop, surrounding the airplane and at some distance from it, was sensitive to the near electromagnetic fields set up by the energized airplane. Intrusions through the outer perimeter of the receiving wire produced perturbations in the received signal that were readily observed. This approach did not depend on choosing an operating frequency corresponding to the characteristic dimension of the aircraft. Thus a frequency could be chosen which would be most affected by an adult intruder.

It is this configuration and its variations that were tested in a field experiment. These full-scale measurements are explained in the next section.

3. FIELD TESTS

In order to establish some of the properties of a radio frequency intruder detection system, a full-scale experiment was set up. A number of sensor configurations were investigated and their detection sensitivity determined under various conditions.

3.1 Description of Experiment

The field tests were conducted on an open grassy field, using a fully enclosed, metal truck trailer (minus the cab) as the physical structure to be protected. Its dimensions and physical design are shown in Figure 2. Because the rear wheels were rubber and the front metal jacks rested on wooden boards, the metal trailer was electrically isolated from the ground. The cable sensors were deployed around the trailer in a circle about 100 ft in diameter.

The detection sensitivity was determined by measuring the response produced when an intruder penetrated the protected zone around the sensor cables. With one exception, the intruders were male adults about 5 ft 10 in. tall who weighed

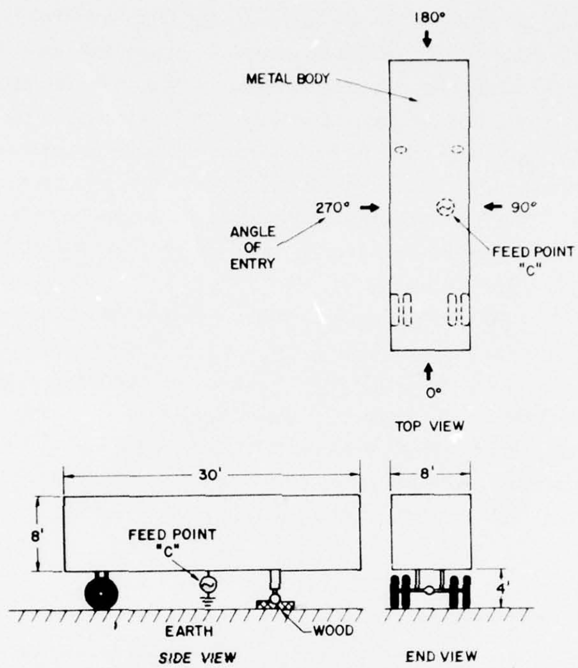

Figure 2. Schematic – Metal Structure for Field Tests

170 lb. The penetrations were made along radials at several positions around the trailer to assess the azimuthal variation in sensitivity.

Most of the measurements were performed at about 75 MHz, which makes an adult intruder about one-half wavelength tall. It was found that very little information is available on the scattering properties of human targets at VHF frequencies. Shultz et al[8] give the radar cross section of a man, but only at frequencies of 410 MHz and above. Some general insight can be obtained by studying the data of radio frequency absorption by animals and bodies of prolate-spherodial shape.[9-11]

8. Schultz, F.V., Burgener, R.C., and Kink, S. (1958) Measurement of the radar cross section of a man, Proc. IRE, 46, No. 2:476-481, February.

9. Gandhi, O.P. (1975) Frequency and orientation effects on whole animal absorption of electromagnetic waves, IEEE Trans. Biomedical Engineering, BME-22, No. 2:536-542.

10. Johnson, C.C., Durney, C.H., and Massoudi, H. (1975) Long-wavelength electromagnetic power absorption in prolate spheroidal models of man and animals, IEEE Trans. Microwave Theory and Techniques, MTT-23, No. 9:739-747.

11. Weil, C.M. (1975) Absorption characteristics of multilayered sphere models exposed to UHF/microwave radiation, IEEE Trans. Biomedical Engineering, BME-22, No. 2:468-473.

Reference 9, Figure 3, page 539 shows the resonant frequency behavior due to RF absorption. Note in that figure the change in the magnitude of the power absorbed and also the change in resonant frequency caused by the different spatial orientations (polarization) of the objects relative to the electrical field. Therefore, the operating frequency must be high enough to cause the system to be sensitive to various intruder orientations yet low enough to discriminate against small animals and birds. The intruder-field interaction is further complicated by the imaging effect of the earth. Unlike frozen or dry soil, high conductivity (wet) earth acts like a good ground plane.

Several sensor cable configurations, which can be grouped into two categories, were investigated. In the first category, the sensor cables were independent of the protected resource. In the other, the resource was an integral part of the detection system. The zone of protection produced by the two types is somewhat different. The independent cable configuration produced a toroidal zone which surrounded the resource while the other enveloped the protected object within a hemispherical zone. Each of these zone patterns has advantages in certain applications.

3.2 Detection Sensitivity Measurements

Consider the independent sensor configuration shown in Figure 3. A pair of cables is connected to a signal source at one end and terminated in a detector at the other. An intruder crossing the cables disturbs the fields thus producing a change in the level of the detected signals. The sensor cables were insulated wires.

The response to intrusions along a number of radials is shown in Figure 4. The response for angles greater than 180° was about the same as those shown for the smaller angles. The variation in response with angle is due to an imbalance in the line near the input-output terminals as well as attenuation of the signals along the line.

Figure 5 shows a variation of the previous configuration. For this test the wires were raised about 1 in. above the ground. Raising the wires produced an increase of about 3 dB in the signal to noise ratio (in one later test, the wires were lowered onto wet soil and the received signal dropped about 12 dB). The unbalanced transmitter and receiver terminals were connected to their respective sensor cable loops with baluns. To compensate for attenuation around the loops, the transmitter and receiver baluns were located 180° apart. Figure 6 shows the response observed with this system and, as expected, the variation in sensitivity with this configuration is substantially less than that observed previously. The unequal amplitude response between entry angles of 90° and 270° is probably due to localized variations in wire location and terrain condition.

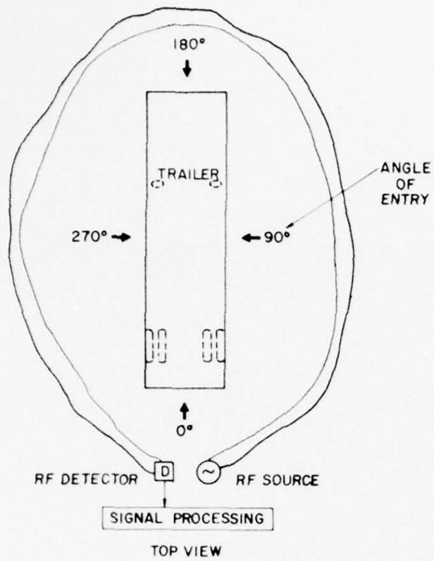

Figure 3. Schematic – Field Layout for Transmission-Line Mode

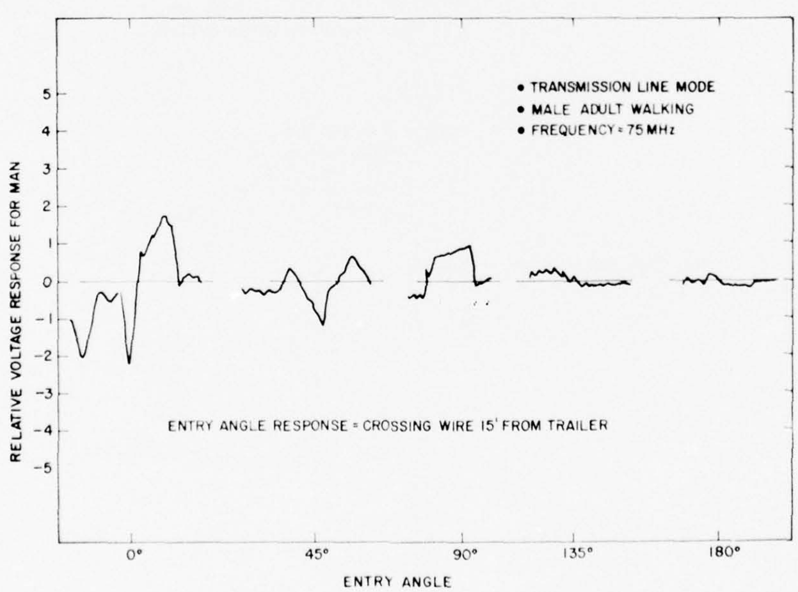

Figure 4. Intrusion Response for Transmission-Line Mode

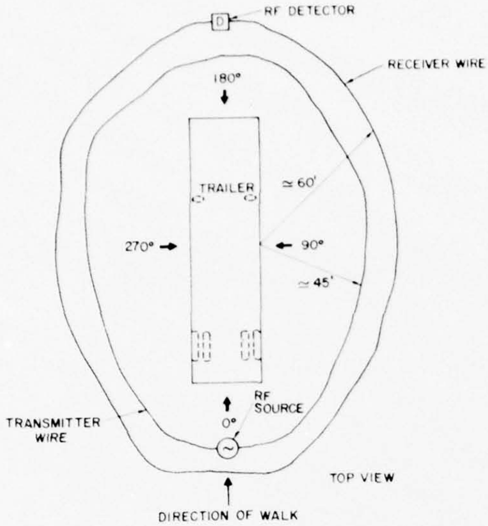

Figure 5. Schematic – Field Layout for Two-Wire Mode

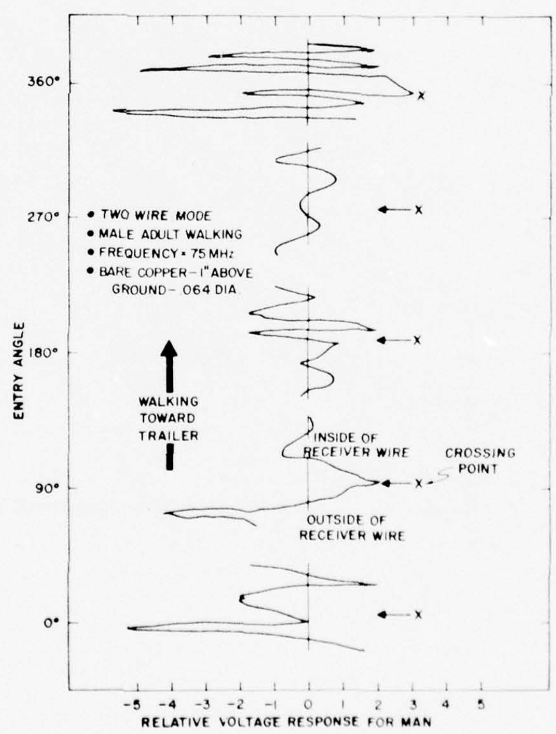

Figure 6. Intrusion Response for Two-Wire Mode

In the two previous configurations the sensor cables operated independently of the protected resource and the sensor fields tended to be localized around the cables. Thus the protected zone surrounded, but did not envelop, the resource. In contrast the next method to be discussed uses the resource (or a separate centrally located antenna) as an integral part of the system. In this case, the object is immersed in the protected zone.

The arrangement shown in Figure 7 used the trailer as an integral part of the detection system. It should be pointed out that any other metallic structure to be protected could be used in the same way. The receiving loop was an insulated wire resting on the ground. The detector was located 180° away from the transmitter feedpoint. Figure 8 shows the amplitude response of an adult male walking around the truck. The detection sensitivity varies considerably with angle. This is mainly due to the shape of the radiated field-strength pattern around the trailer.

Additional tests were conducted with this system to determine its response to an intruder walking, creeping, crawling, and rolling along a radial path. The results are shown in Figures 9 and 10. As can be seen, response at the point of crossing decreases as the penetrator goes from an upright position to a rolling one. However, intrusions are detected at distances up to 30 ft for the creeping and approximately 15 ft for the rolling positions.

The previous measurements (Figure 8, at 82 MHz) were repeated with the receiving wire raised about 1 in. above the ground and the operating frequency changed to 75 MHz. The results shown in Figure 10 indicate that the system sensitivity has increased measurably.

A more uniform angle coverage was obtained by feeding the trailer from the center instead of from the end. Comparison of the response shown in Figure 11 with that of Figure 8 clearly shows the improvement.

The preceding measurement results were principally concerned with the RF field distributions and the response to their perturbation. In any practical system, these responses must be sorted out and classified so that only signal variations caused by human intruders are recognized. This discrimination is easily implemented by passing the detected signals through a bandpass filter followed by an amplitude comparator.

Such a processing system is shown in Figure 12, connected to the output of the radiating configuration discussed in connection with Figure 7. For this experiment the trailer was center fed and the receiving loop was a single wire divided into two segments. The received signals were fed into a simple combining network without regard to their relative amplitude or phase. After detection, the signal passed through a bandpass filter (typically .01 to 10 Hz) which removed components produced by nonhuman, environmental, or physical disturbances and greatly decreases the false-alarm rate.

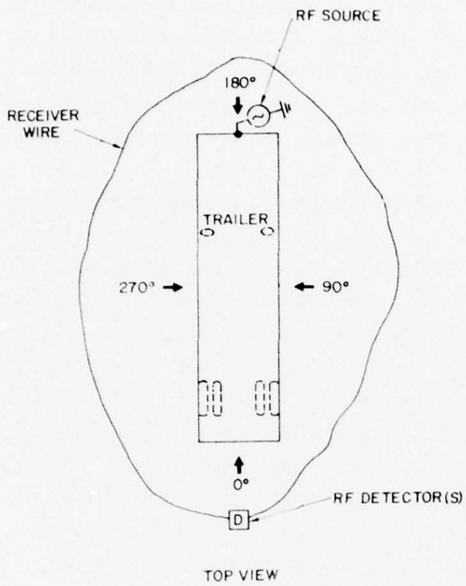

Figure 7. Schematic – Field Layout for End-Fed Mode

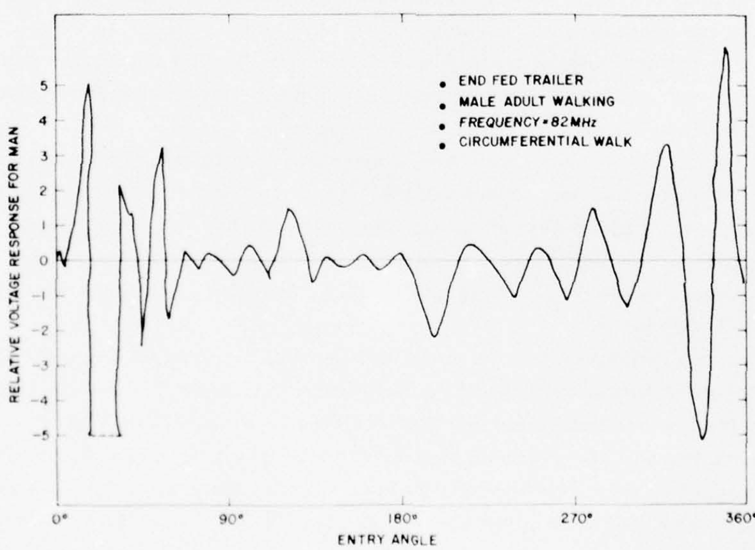

Figure 8. Intrusion Response for End-Fed Mode

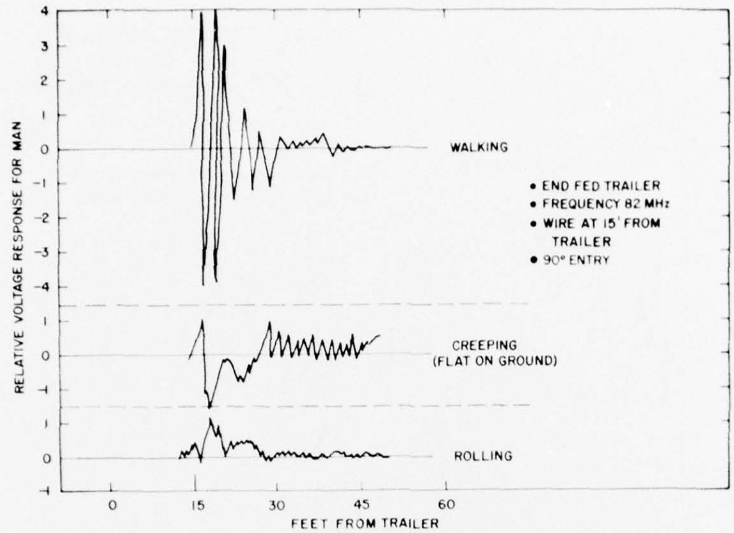

Figure 9. Intrusion Response – End-Fed Mode (Walk, Creep, Crawl)

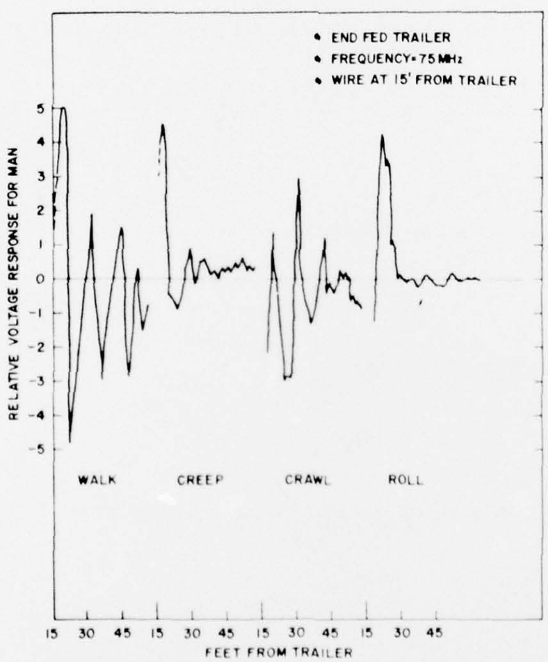

Figure 10. Intrusion Response – End-Fed Mode (Walk, Creep, Crawl, Roll)

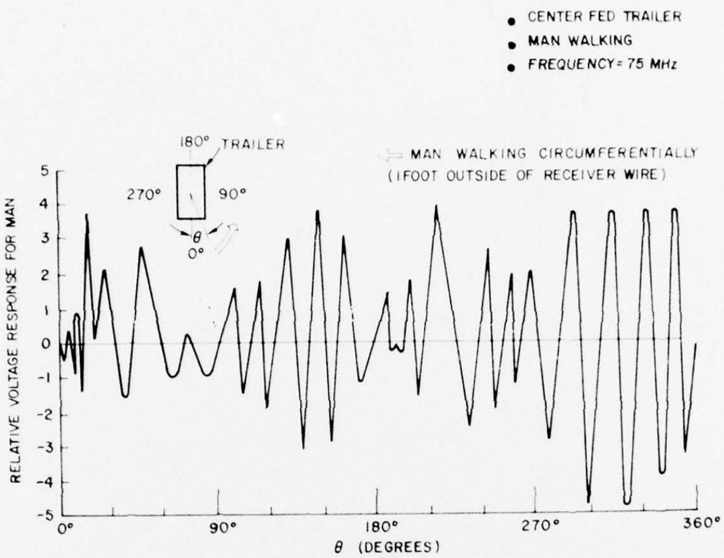

Figure 11. Circumferential Response of Vehicle Intruder Protection System

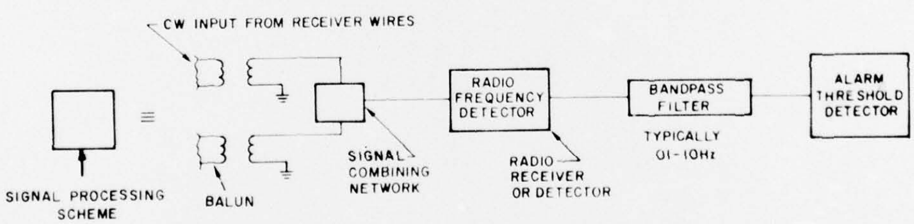

Figure 12. Signal Processing Circuitry

From the filter, the signal is passed into an amplitude comparator which triggers an alarm when preset threshold levels are exceeded by the detected signal voltages. The waveforms shown for the system response voltages were obtained by recording the detected signals prior to filtering and thresholding. One modification to the system is to phase the input signals so that they are cancelled in the summing tee, greatly reducing the carrier amplitude level at the input to the radio receiver. This allows a larger receiver gain to be used with a corresponding increase in detection sensitivity. In this way any of the smaller amplitude fluctuations caused by an intruder are more easily detected. Measurements with this system showed that intruder detection occurred for any angle.

Figure 13A shows an entry attempt in which the intruder approached the protected structure along one radial. The threshold levels for this test were set at ±2V. Any detected signal excursion of this amplitude, in the passband of the filter, would trigger an alarm. As shown, the alarm was first triggered at approximately 25 ft from the receiving wire or about 50 ft from the protected structure. As entry continued, the voltage fluctuations caused by the intruder continually exceeded the alarm threshold levels, peaking when the intruder was between the trailer and the receiver wire. This demonstrates the concept that in this configuration the protected resource is immersed in the protected zone.

A concern with any external security system is the frequency of false alarms; *that is*, triggering of the alarm either by natural events (mainly environmental) or by birds and small animals. Figure 13B shows the voltage *perturbations* caused by a dog (a L'hasa Apso, weight approximately 15 lb, overall dimensions approximately 18 in. by 10 in. by 6 in. wide). The system discrimination was sufficient to produce no alarms even when the dog tripped over the receiving wire.

Figure 14 shows the results of an intrusion attempt in which an intruder attempted to cross the receiver wire at some height above the wire. This condition would exist in an overt attempt to defeat the system or if the sensor cables were under several feet of snow. Two wooden stepladders (one on each side of the receiver wire and 10 ft apart) supported a wooden plank 5 ft above the ground. The intruder climbed one ladder, walked across the plank, and descended on the opposite ladder. Though the shape of the response was different, the alarm was triggered.

For detection systems exposed to various environmental conditions, data on the effects of weather such as rain, snow, and ice is vital. Figure 15 compares, for various entry angles, the system response when the receiver wire lay on dry earth and when it was covered by approximately 6 to 9 in. of snow. Although the details of the responses vary, the intrusions are clearly detected. Figure 16 shows the response to a man walking and then crawling over the snow covered wire. Though the response diminished for the crawling mode, it was still clearly detectable.

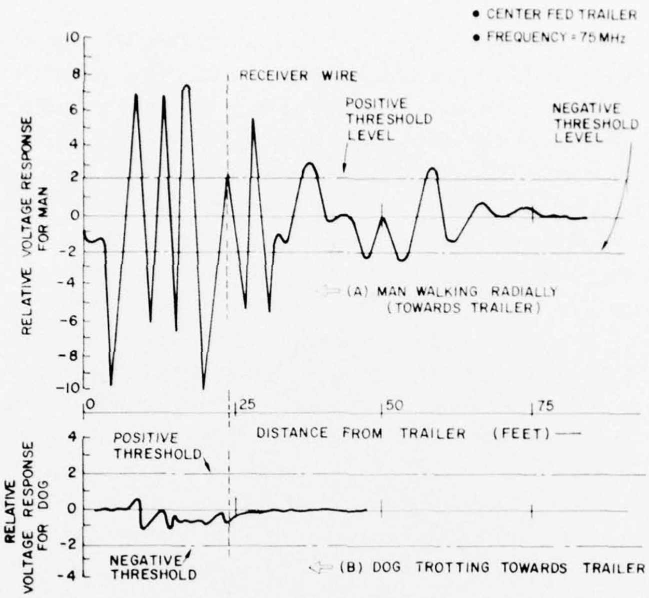

Figure 13. Radial Response of Vehicle Intruder Protection System

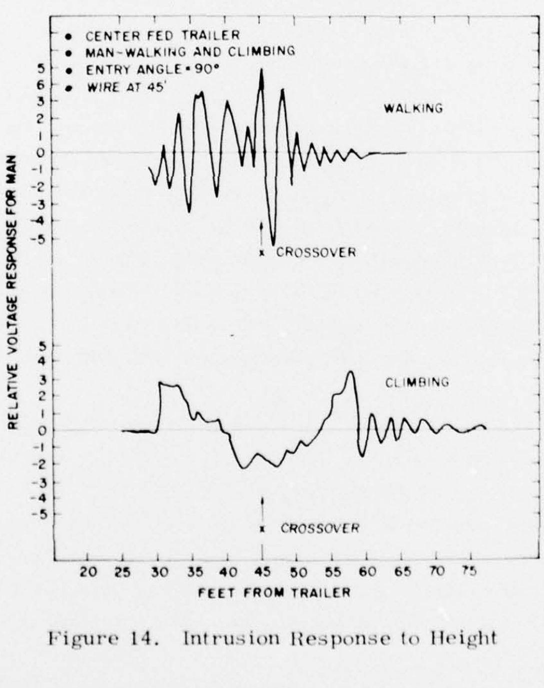

Figure 14. Intrusion Response to Height

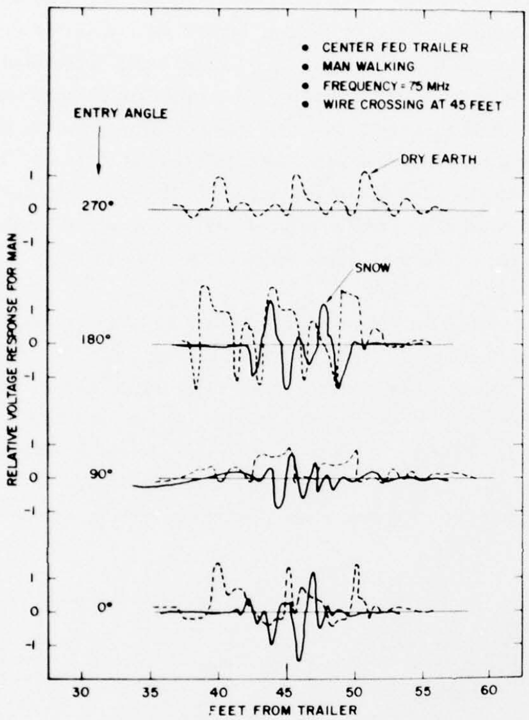

Figure 15. Intrusion Response – Dry Earth and Snow

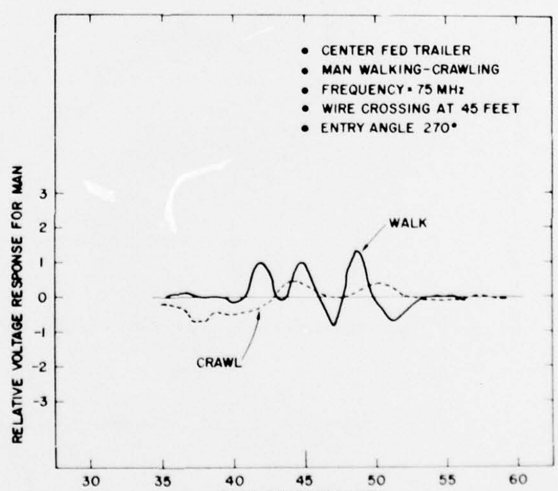

Figure 16. Intrusion Response – Receiver Wire Under Snow

Although snow affected system response, both by decreasing detection sensitivity and by changing the detailed shape of the response, it was still possible to detect intruders over the range of conditions tested. Some brief tests were also conducted to determine system response to the presence of a metallic object moving within the zone of protection. For this test, an adult periodically raised a foil covered box 1 ft by 1 ft by 6 ft long over his head and then back to his knees. The long dimension of the box remained parallel to the ground while the box was moved from an initial height of 3 ft to about 7 ft above the ground. The man stood erect during this exercise and only moved his arms up and down at the rate of once every 2 sec.

The results of these measurements for two orientations of the box at each of two azimuth angles are presented in Figure 17. The interesting point to notice here is that the system is not operating as an omnidirectional radiator surrounded by a simple loop receiving antenna. For if this were the case, the ratio of radial response to transverse response (R/T) would be expected to remain reasonably constant as the azimuth angle was changed. The fact that the (R/T) < 1 for 0° and (R/T) > 1 for 90° indicates that the structure has a complex polarization pattern.

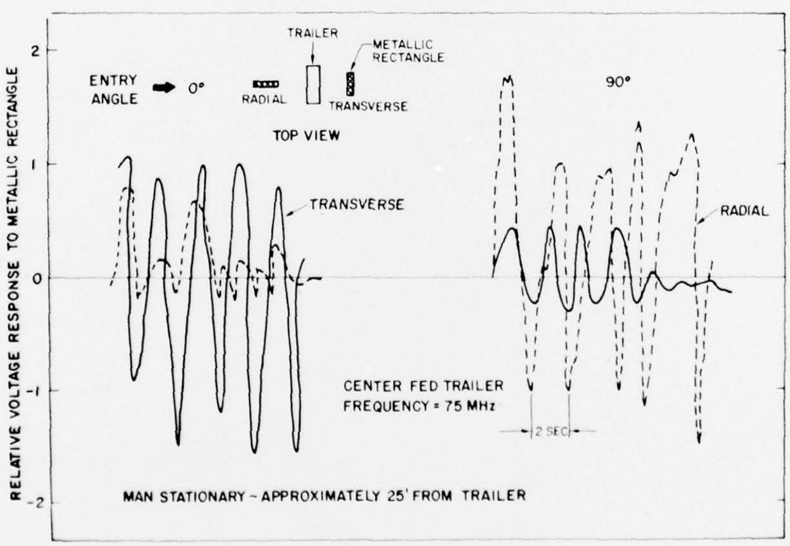

Figure 17. System Response to Polarization

4. DISCUSSION

The measurement results that have been presented clearly show the validity of using signals in the VHF range for the detection of intruders. The signals are relatively unaffected by large variations in ambient environmental conditions and interact strongly with human (size) targets.

These preliminary measurements have demonstrated the basic operational properties of such systems and have identified a number of areas where performance could be greatly improved. For example, the receiving and transmitting cables had high attenuation when operated on the ground. This problem could be eliminated by using leaky coaxial cables such as CERT* or Radiax.** In other applications, simply raising the sensor loops a few inches off the ground would be adequate.

The signal processing used in the experiment was simple although, in fact, perfectly suitable for practical application. An operational system should have additional features such as a long time constant AGC, BITE, CFAR, jamming alarms, and performance monitors. All of these are well known techniques which could be easily incorporated into an operational system.

There are a number of measurements which have yet to be made. These include measurements around aircraft to determine the effect of wing motion and radiation pattern modification; the effect of various ground compositions on cable sensitivity; the variation in the scattering cross section of humans with position; and the polarization properties of the system as a whole. But these are expected simply to add to the information base and not to disclose serious performance deficiencies.

After these experiments were completed, some additional measurements were performed to determine the forward scattering cross section of humans in the VHF range. These measurements were conducted over a ground plane and repeated over earth. Scattering data was obtained over the frequency range 30 to 450 MHz for humans in upright, kneeling, and lying positions. The ground plane results, for an erect adult about $\lambda/2$ tall, showed a large amount of structure with peaks of varying amplitude occurring at frequencies roughly corresponding to $\lambda/2n$, $n = 0, 1, 2 \ldots$. An overall rise in cross section with increasing frequency was also apparent. The general shape of the cross section vs frequency curve over earth was similar to that obtained over the ground plane with two important differences. First, the lossy earth limits the resonance effects causing the variation in cross section over the frequency range to be greatly reduced. Second, the

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*CERT: Trade name. Times Wire and Cable, Wallingford, Ct 06492

**RADIAX: Trade name. Andrews Corp., Orlando Park, Ill. 60462

average cross section is considerably lower but its steady increase with frequency is still apparent. In both cases, the cross section dropped off sharply below about 50 MHz.

The results of these measurements and the full-scale experiment indicate that the specific operating frequency is not critical so long as it is high enough to interact strongly with an adult intruder.

It turned out that the instrumentation required for implementing the independent sensor configuration that produces a toroidal zone of protection is the same as that required for the independent sensor configuration that provides hemispherical coverage. Thus, only the design of the sensor cables need be modified in the two methods. Also the exact placement of the cables or central transmitting antenna does not appear to be critical. The techniques can be applied to the protection of aircraft, structures, or even open areas. It can be permanently installed or carried and deployed temporarily as needed.

A follow-on program is underway to investigate all of the areas where additional data is required. Detailed measurements of several cable types, sensor configurations, and signal processing methods are being made.

5. SUMMARY

Radio frequency intruder detection is a viable option to provide protection for a wide variety of isolated high value resources. The technique provides inherent discrimination between human intruders and small animals. It is not affected by rain, snow, fog, or other variations in conditions. Slow changes in environmental factors are easily compensated for and rapid fluctuations can be filtered out producing a system with high detection sensitivity and a low false-alarm rate.

References

1. Burngard, D.R. et al (1973) Equipment Description of a Mobile Laser Fence for Aircraft Security, Working Paper No. 5430, Dept D-82, The Mitre Corporation.

2. Monostatic Infrared Intrusion Detector "MIRID" (1970) Engineering Bulletin, Motorola/Government Electronics Division, 17, No. 2:18-21.

3. Mid-Range Microwave Intruder Detector, Shorrock Security Systems, Ltd, North American Office, 1815 North Fort Myer Drive, Suite No. 1002, Arlington, VA 22209.

4. Lightweight Portable Microwave Barrier Type Intrusion Sensor "AIDS-300," General Dynamics, Electronics Division, P.O. Box 81127, San Diego, CA 92138.

5. Woode, A.D. and Charters, J.S.T. (1976) Microwave Systems News, August/September, pp 113-118.

6. Outdoor Microwave Link, Model 300, Omni Spectra, Inc., Security Products, 1040 West Alameda Drive, Tempe, Arizona.

7. Tanner, R.L. (1957) Shunt-Fed and Notch-Fed H-F Aircraft Antennas, AFCRC-TN-57-582, AD 133622, Stanford Research Inst., Menlo Park, CA.

8. Schultz, F.V., Burgener, R.C., and Kink, S. (1958) Measurement of the radar cross section of a man, Proc. IRE, 46, No. 2:476-481, February.

9. Gandhi, O.P. (1975) Frequency and orientation effects on whole animal absorption of electromagnetic waves, IEEE Trans. Biomedical Engineering, BME-22, No. 2:536-542.

10. Johnson, C.C., Durney, C.H., and Massoudi, H. (1975) Long-wavelength electromagnetic power absorption in prolate spheroidal models of man and animals, IEEE Trans. Microwave Theory and Techniques, MTT-23, No. 9:739-747.

11. Weil, C.M. (1975) Absorption characteristics of multilayered sphere models exposed to UHF/microwave radiation, IEEE Trans. Biomedical Engineering, BME-22, No. 2:468-473.

Appendix A

Categorization of Intrusion Detection Modes Investigated During Model Measurements

The purpose of this section is to list some of the many RF techniques that were investigated in the course of this study. The measurements can be divided into two broad categories as shown below:

I. Contact Coupling
   A. Contact Detection
      1. Tuned-Circuit Mode
      2. Reflection Mode
      3. Transmission Mode
   B. Noncontact Detection
      1. Perimeter-Loop Mode

II. Noncontact Coupling
   A. Noncontact Detection
      1. Induced-Resonance Mode
      2. Independent-Radiator Mode
      3. Two-Loop Mode

The distinguishing characteristic of contact coupling is that the structure to be protected is physically connected to the RF source; in noncontact coupling it is not. Noncontact coupling also includes the case of no coupling when the object is not part of the RF system. Most of the configurations to be mentioned were implemented in both balanced and unbalanced configurations.

Three variations were investigated in which the detector was connected directly to the object. In the Tuned-Circuit Mode it was the impedance that was monitored to indicate an intrusion. The Reflection Mode and the Transmission Mode are closely related. Here the aircraft served as one side of a transmission line. A variety of conducting structures placed under the plane were used for the other element of the transmission line. In the Reflection Mode it was the reflected power that was monitored; in the Transmission Mode it was the transmitted power.

Another configuration placed a loop of wire around the aircraft. This Noncontact Detection monitored the power coupled to the loop.

The Noncontact Coupling experiments each used noncontact detection for monitoring. In the Induced-Resonance Mode, the aircraft model was energized with dipole or loop antennas placed in close proximity. The Independent Radiator Mode does not depend on the electrical or physical properties of the structure to operate. An independent radiating system, typically one or more monopoles, is used in conjunction with a perimeter receiving loop. The two-loop mode uses a pair of concentric loops 2 to 8 ft apart. One serves as a transmitting loop and the other as a receiving loop.

Appendix B

An Impedance Method for Intruder Detection at Microwave Frequencies

The tuned circuit mode was tested on the model airplane and on a full scale automobile (Dodge Dart, 1972 model, see Figure B1 for dimensions.) The schematic of the experimental setup is shown in Figure B2. The impedance of the system is translated through the coaxial cable to the impedance bridge. An intruder changes the system impedance thus upsetting the null condition and indicating the intrusion. Various combinations of feed locations and ground elements were tried. These included a 3 ft by 3 ft aluminum plate beneath the auto and a metal stake driven into the ground beside the auto. These variations appeared to be of lesser consequence to overall system performance than the fact of operating the tuned mode. Maximum sensitivity to an intrusion by an adult occurred at a frequency of approximately 30 MHz, with a lesser response at 60 MHz. The ratio of length of car to wavelength was approximately 0.5 and 1.0, respectively. For a 6-ft man, the height to wavelength ratio was about 0.2 and 0.4, respectively. The pattern of the response varied depending on the location of the feed point, although detection sensitivity remained high for all intrusion directions. Maximum detecting distances averaged almost 8 ft from the car. A few times during the experiments an anomalous effect occurred in which the coaxial cable began to radiate, became sensitive to intrusion attempts, and upset the null condition of the bridge. Though troublesome at times, this effect could perhaps be used in some specialized detection scheme.

One other technique was tried on the car. Attempts were made to energize (resonate) the car indirectly by bringing into its proximity a dipole (or a loop). A similar device was used for receiving the signal. The results of these tests were inconclusive.

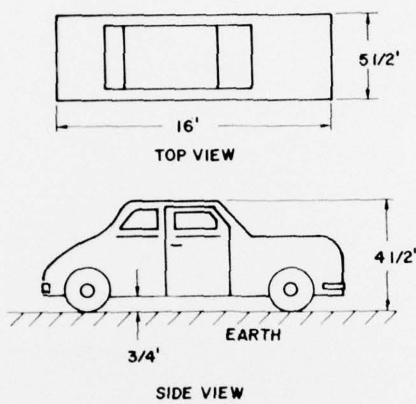

Figure B1. *Schematic* – Field Test Auto

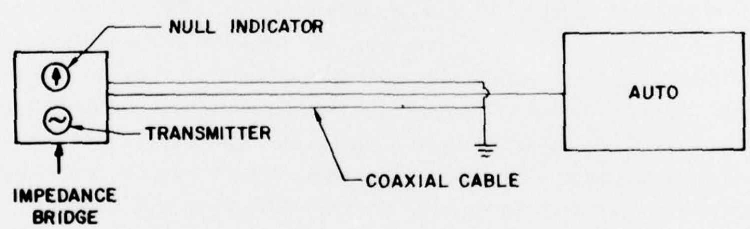

Figure B2. Schematic – Experimental Setup for Tuned Circuit Mode

METRIC SYSTEM

BASE UNITS:

Quantity	Unit	SI Symbol	Formula
length	metre	m	...
mass	kilogram	kg	...
time	second	s	...
electric current	ampere	A	...
thermodynamic temperature	kelvin	K	...
amount of substance	mole	mol	...
luminous intensity	candela	cd	...

SUPPLEMENTARY UNITS:

plane angle	radian	rad	...
solid angle	steradian	sr	...

DERIVED UNITS:

Acceleration	metre per second squared	...	m/s
activity (of a radioactive source)	disintegration per second	...	(disintegration)/s
angular acceleration	radian per second squared	...	rad/s
angular velocity	radian per second	...	rad/s
area	square metre	...	m
density	kilogram per cubic metre	...	kg/m
electric capacitance	farad	F	A·s/V
electrical conductance	siemens	S	A/V
electric field strength	volt per metre	...	V/m
electric inductance	henry	H	V·s/A
electric potential difference	volt	V	W/A
electric resistance	ohm		V/A
electromotive force	volt	V	W/A
energy	joule	J	N·m
entropy	joule per kelvin	...	J/K
force	newton	N	kg·m/s
frequency	hertz	Hz	(cycle)/s
illuminance	lux	lx	lm/m
luminance	candela per square metre	...	cd/m
luminous flux	lumen	lm	cd·sr
magnetic field strength	ampere per metre	...	A/m
magnetic flux	weber	Wb	V·s
magnetic flux density	tesla	T	Wb/m
magnetomotive force	ampere	A	...
power	watt	W	J/s
pressure	pascal	Pa	N/m
quantity of electricity	coulomb	C	A·s
quantity of heat	joule	J	N·m
radiant intensity	watt per steradian	...	W/sr
specific heat	joule per kilogram-kelvin	...	J/kg·K
stress	pascal	Pa	N/m
thermal conductivity	watt per metre-kelvin	...	W/m·K
velocity	metre per second	...	m/s
viscosity, dynamic	pascal-second	...	Pa·s
viscosity, kinematic	square metre per second	...	m/s
voltage	volt	V	W/A
volume	cubic metre	...	m
wavenumber	reciprocal metre	...	(wave)/m
work	joule	J	N·m

SI PREFIXES:

Multiplication Factors	Prefix	SI Symbol
1 000 000 000 000 = 10^{12}	tera	T
1 000 000 000 = 10^{9}	giga	G
1 000 000 = 10^{6}	mega	M
1 000 = 10^{3}	kilo	k
100 = 10^{2}	hecto*	h
10 = 10^{1}	deka*	da
0.1 = 10^{-1}	deci*	d
0.01 = 10^{-2}	centi*	c
0.001 = 10^{-3}	milli	m
0.000 001 = 10^{-6}	micro	μ
0.000 000 001 = 10^{-9}	nano	n
0.000 000 000 001 = 10^{-12}	pico	p
0.000 000 000 000 001 = 10^{-15}	femto	f
0.000 000 000 000 000 001 = 10^{-18}	atto	a

* To be avoided where possible.